Design of foreign object debris detecting and monitoring using two sets of sensor system

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ABSTRACT

Foreign object debris (FOD) is a foreign object that should not be on the runway which might cause the risk of aircraft crashes and put the lives of humans at risk. In this research, we designed a system to detect FOD using two sets of a sensor system for a wider, area of detection. This research was commenced by designed the entire hardware and software and tested the system. The object used as the testing object were rock, bolts, plastic bottles as well as iron pieces with varied distances and position angles. Based on the testing result, both sets of sensor system could detect objects with distance accuracy on the sensor system set of FOD 1 and FOD 2 consecutively were 98% and 94% for rock, 97% and 96% for bolts, 96% and 94% for plastic bottles, 96% and 94% for the iron pieces. The accuracy of angle measurement on the sets of sensor system FOD 1 and FOD 2 consecutively were 96% for rock, 98% for bolts, 97% and 95% for plastic bottles, 97% and 94% for the iron pieces. Monitoring system testing was carried out using black box testing and website response speed test towards the variation of database number.

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1. INTRODUCTION

Foreign object debris (FOD) is a thread in the aviation industry in the form of foreign objects existing in the area of flight with the potential to cause damage to the aircraft [1]–[5]. Aircraft crash caused by FOD that killed 113 people once occurred to French flight 4,590 in 2,000 in which it was estimated to cause up to USD 4 billion [6]. To anticipate such a thread, airports in Indonesia still use the manual system to monitor the runway using patrol vehicles and the crews as the observers. Such monitoring usually is carried out once a month so that the possible rate of the accident to occur is still high and there was also a possibility of human error in a manual monitoring system. To increase security, stricter prevention efforts need to be carried out, one of which was by sweeping the flight area 3 times a day manually. However, the manual sweeping must be done by stopping the flight schedule during the activity which could cause a loss on the aviation industry in the form of the interference of flight schedule and the potential of the existence of FOD remained that could be predicted [7]. Therefore, a technology needed to be developed that can detect in real-time and does not interfere with flight schedules.

Several several kinds of research had been carried out by researchers, some of which used millimeter wave system radar [8]–[10] or ultrasonic sensor as distance detector combined with an infrared camera to detect the object type [11], yet such systems were not able to provide the real visual image of the object. There was also a system that only used a camera [12]–[15], this system, however, could not provide direct information about the position. To obtain the information on the position, a huge number of cameras were required along the runaway.

Light detection and ranging (LiDAR) is a sensor that could provide information of the objection position by sending light waves on the object and recaptured by the sensor [16], [17]. LiDAR technology could be combined with a warning alarm so that when there was an object detected, the alarm would go on [18]. Meanwhile, to capture object image IP camera can be used as it could transfer the data or convert recorded video files into a digital file that could be accessed through the internet using an IP address determined in advance. Currently, detection using image processing could be developed by easily accessing the website [19]. To control LiDAR and IP camera and to display the image on the web page, we could use a small-sized computer or Raspberry Pi [20], [21] with the programming language Python [22], [23].

In this research, we restudy the previous researches by combining technologies that could be used to detect FOD, by LiDAR, IP camera, and Raspberry Pi. Information data about FOD that have been detected would then be displayed on the website. Ideally, a sensor set must be installed on the left and right of the runway with the distance adjusted to the distance covered by the sensor set. For example, the smallest dimension of a runway was 92 meters in length and 18 meters in width [24]–[26]. To cover this area, 20 sets of the sensor with LiDAR and IP camera detection range of 10 meters were required. However, in this research, we only used two sets of the sensor, where for the actual system we could just replicate as many as we need. This research has a very high contribution to air transportation related to flight safety. FOD will provide information on the existence of unwanted objects on the runway which will cause an aircraft accident. So, this research is very important to do with the development of both hardware and software.

2. METHOD

The devices used in this research were LiDAR lite V3, IP camera, motor servo, Raspberry Pi, and Python programming language. The object for the experiment test used was rock, used plastic bottles, bolts, and iron pieces. The research was carried out by designing a FOD sensor device. Further, sensor device placement was done based on the distance determined and the experiments were carried out in the range of those two sensor devices.

2.1. Design of hardware

In general, a system block diagram designed could be seen in Figure 1. The working principle of the system is as follows: motor servo would spin LiDAR with the determined angle, LiDAR then would detect the surrounding area with lightwave emission. When one of the LiDARs detected an object around it, Raspberry Pi would process the signal that was sent and stored the data information such as distance and the position angle of the object. Furthermore, Raspberry Pi would send the signal to IP camera to zoom in and capture the image of the object. The system was set to such an extent on the hexagonal board, with the front, left, and right sides opened. The bottom part of the board was compiled Raspberry Pi and the connecting cable to other Raspberry Pi device in a 9 cm × 8 cm × 3 cm black box and motor servo that had been assembled with LiDAR was placed in the front part of the board with ±1 cm distance above the ground. The distance of both sensor system devices was 5 meters. Sensor system device design could be seen in Figure 2.

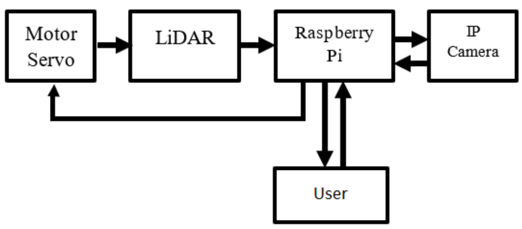

Figure 1. Block diagram

Figure 2. Sensor system device design

2.2. Design of software

The development of FOD monitoring software was divided into several stages namely the analysis of need, design, coding, and testing. The analysis of need was carried out by observing the data produced by both detection sensor system devices in the form of data information of distance, angle, time of detection and the image of the object detected. The data was then displayed on a web page in the form of information data that could be accessed by the users. The need analysis produces website features as shown in Table 1.

Table 1. Website features

No.	Feature
1.	Tool option
2.	“Distance” column
3.	“Detection angle” column
4.	“Time detection” column
5.	“FOD image” column
6.	Sort
7.	Search
8.	Show
9.	Pagination

From the analysis result, we designed the website in the form of a display that would be accessed by the users. The website design was adjusted to the features required so that it had the display as shown in Figure 3. Program code was written in HTML, PHP, CSS, JavaScript, SQL, and Python programming language, where the algorithm followed the flowchart in Figure 4.

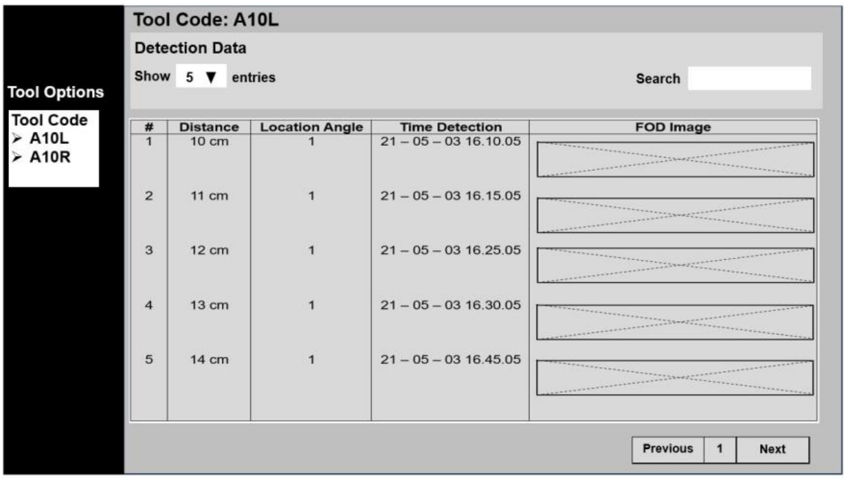

Figure 3. Web page design

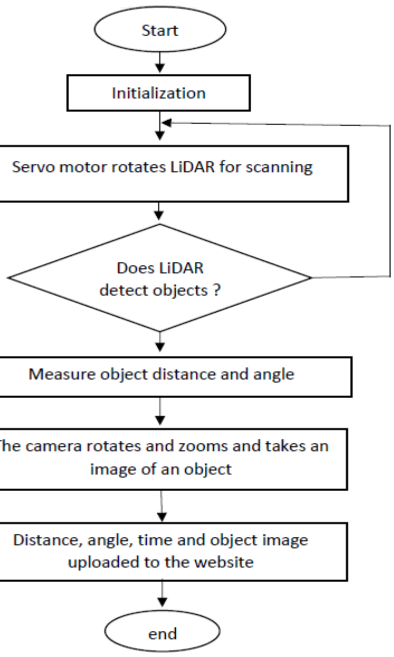

Figure 4. System flowchart

3. RESULTS AND DISCUSSION

We have been through some processes, some of which were designing processes followed by assembling two sensor system devices. The next process was designing and implementing the software so that the system followed the instruction given. We present the system testing that we have built namely detection system testing and monitor system testing.

3.1. Testing FOD sensor system device

We gave name to each sensor system device as sensor system FOD 1 and sensor system FOD 2 to make easy in analyzing the result obtained. The testing was carried out in a wide field so that the detection system was uninterrupted by the surrounding area where the placement of both sensor system devices had 5 meters in distance. In front of both systems, an object was placed as the testing material in the area that would be detected by the sensor system device. Then, the detection system program and the monitor were run through the Raspberry Pi terminal until the initial display as shown in Figure 5 appeared.

Figure 5. Initial display of input webpage

The initial display of the menu showed the parameter such as the height of the IP camera, distance covered, minimum and maximum angle as well as distance check menu which functioned to see the maximum distance in detection. The height unit of the IP camera was the distance between IP camera and LiDAR and it could also be filled based on the condition. The menu of distance covered indicated the unit of object distance range in front of the system that would be detected after passing through the distance check menu as the reference. On the menu of minimum and maximum angles, the targeted angle could be input. Once the entire parameter is input, the sensor system device could be run by pressing the button to start the detection, then the sensor system device would work based on the parameter input.

The objects used for testing were rock, bolts, used plastic bottles, and iron pieces. These objects were positioned with the distance and angle that had been determined from the FOD 1 and FOD 2 sensor system device. Detection was carried out in steps, started from FOD 1 to a certain object and continued by FOD 2 system based on the detection parameter input. As for the detection parameter that had been input in, could be seen in Table 2.

Table 2. System testing parameter

Parameter	Value
Camera height	27 cm
Range distance	500 cm
Starting angle	-50 ^{o}
Final angle	50 ^{o}

Once variable FOD 1 and FOD 2 were done input and the start button was pressed, then the motor servo would move to spin with LiDAR that would detect the area in front of it, and then the IP camera moved to the position determined if there was an object detected. Meanwhile, when the stop button was pressed, then the system would automatically stop. The detection process of both sensor system devices was done in turn. Once the scanning area on each sensor system device was done, the result could be seen through the system database page by entering the IP address in the browser page used. On the page, there was information about object distance detected, position angle detected, the time of image captured, and the image itself. The page also enabled opening the image fully displayed on the browser page. As for the accuracy of distance measurement and the angle on FOD 1, FOD 2, and FOD 1 and FOD 2 at the same time, could be seen in Tables 3-5.

Table 3. The accuracy of FOD 1 sensor system device

Object	Distance (cm)	Distance measured by the system (cm)	Accuracy (%)	Angle (˚)	Angle measured by the system (˚)	Accuracy (%)
Rock	100	97	97	0	0	100
Rock	300	297	99	0	0	100
Rock	400	377	94	-40	-45	87
Rock	400	401	100	40	37	82
Rock	500	490	98	0	0	100
Bolt	100	86	86	0	0	100
Bolt	300	302	99	0	0	100
Bolt	400	403	99	-40	-43	92
Bolt	400	400	100	40	41	97
Bolt	500	506	99	0	0	100
Iron pieces	100	91	91	0	0	100
Iron pieces	300	311	94	0	0	100
Iron pieces	400	390	97	-40	-43	92
Iron pieces	400	389	97	40	38	95
Iron pieces	500	490	98	0	0	100
Plastic bottles	100	97	97	0	0	100
Plastic bottles	300	310	97	0	0	100
Plastic bottles	400	407	98	-40	-42	95
Plastic bottles	400	371	93	40	43	92
Plastic bottles	500	480	96	0	0	100

Table 4. The accuracy of FOD 2 sensor system device

Object	Distance (cm)	Distance measured by the system (cm)	Accuracy (%)	Angle (˚)	Angle measured by the system (˚)	Accuracy (%)
Rock	100	95	95	0	0	100
Rock	300	285	95	0	0	100
Rock	400	375	93	-40	-45	87
Rock	400	448	88	40	37	92
Rock	500	490	98	0	0	100
Bolt	100	100	100	0	0	100
Bolt	300	291	97	0	0	100
Bolt	400	439	90	-40	-41	97
Bolt	400	403	99	40	43	92
Bolt	500	539	92	0	0	100
Iron pieces	100	95	95	0	0	100
Iron pieces	300	305	98	0	0	100
Iron pieces	400	391	97	-40	-35	87
Iron pieces	400	489	78	40	35	87
Iron pieces	500	505	99	0	0	100
Plastic bottles	100	115	85	0	0	100
Plastic bottles	300	310	97	0	0	100
Plastic bottles	400	372	93	-40	-42	95
Plastic bottles	400	395	99	40	49	77
Plastic bottles	500	512	98	0	0	100

Table 5. The accuracy of FOD 1 and FOD 2 sensor system device at the same time

Object	Distance (cm)	Distance measured by the system (cm)	Accuracy (%)	Angle (˚)	Angle measured by the system (˚)	Accuracy (%)
Rock	391	392	100	40	37	92
Rock	391	366	94	-40	-45	87
Bolt	391	391	100	40	41	97
Bolt	391	430	84	-40	-41	97
Iron pieces	391	380	97	40	38	95
Iron pieces	391	382	98	-40	-35	87
Plastic bottles	391	362	93	40	43	92
Plastic bottles	391	363	93	-40	-42	95

From the result of the testing process using both sensor system device, the average accuracy of both sensor system devices in each object were as follows: on FOD 1 sensor system device: on the object of rock, the average accuracy for the distance was 98% and for the angle of object's position was 96%, on the object of a bolt, the average accuracy for distance was 97% and for the angle of object's position was 98%, on the object of a plastic bottle, the average accuracy for the distance was 96% and for the angle of object's position was 97% and on the object of iron pieces, the average accuracy for the distance was 96% and for the angle of object's position was 97%. On FOD 2 sensor system device: on the object of rock, the average accuracy for the distance was 94% and for the angle of object's position was 96%, on the object of a bolt, the average accuracy for distance was 96% and position angles was 98%, on the object of a plastic bottle, the average accuracy for the distance was 94% and for the angle of object's position was 95% and on the object of iron pieces, the average accuracy for the distance was 94% and for the angle of object's position was 94%.

Based on the testing result, it was identified that both sensor system device was able to detect object with a maximum distance of 5 m. There was an area detected by both sensor system devices with a 4 m distance with 40 degrees angle from the sensor system device FOD 1 and -40 degrees from the FOD 2 sensor system device that was considered as a critical area. Several spots that could not be detected by both sensor system devices were because the distance and the position angle of the object exceeded the distance covered that had been determined so that they were undetected by both devices of the sensor system. The position of such placement could make the system detect its area more optimally and would not detect the object at the same position by other sensor system devices except on the critical spot from both systems.

3.2. Monitor system testing

The display result of the website page that had been made provided some features customized to the website requirements. As for the website page display that had been made could be seen in Figure 6. The process of testing website features was carried out using the black-box testing method. This testing was carried out by performing actions on all available features on the website. The result of testing the features on the data displaying website page was shown in Table 6.

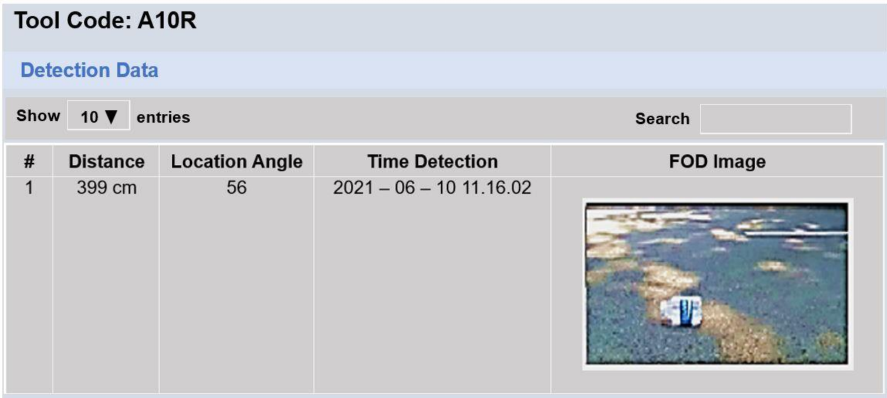

Figure 6. Website page display

Table 6. Testing result of website page

Testing activities	Expected realization	Test result	Conclusion
Click the show button and choose the amount of data	The data displayed on the website page is only on demand	The data displayed on the website page is only on demand	Accepted
Fill in the "Search" column	The data is sorted and only displays the data you are looking for	The data is sorted and only displays the data you are looking for	Accepted
Click the "Sort" button	The data will be sorted from largest to smallest or vice versa	Data is sorted from largest to smallest or vice versa	Accepted
Click the pagination button (previous, number, and next)	The page will be redirected according to our wishes	The page is directed according to the number clicked	Accepted
Click the scroll to a top button when the page is scrolled down	Back again to the top of the website	Back again to the top of the website	Accepted
Access via cell phone	Display according to cell phone screen size	Display according to cell phone screen size	Accepted

Based on both Tables 3-5, it could be concluded that the features on the website page could work based on the plan. The testing of website response time was carried out by observing the response time on the website when opening the page of the website with the variation of data number on the database. The variation of data number on the database was carried out to observe the change of response time when opening the website page with various data numbers where the variation was 1, 100, 200, 500, 1,000, 2,000, 3,000, 4,000, and 5,000 data simulated as FOD. The result of this testing could be seen in Figure 7.

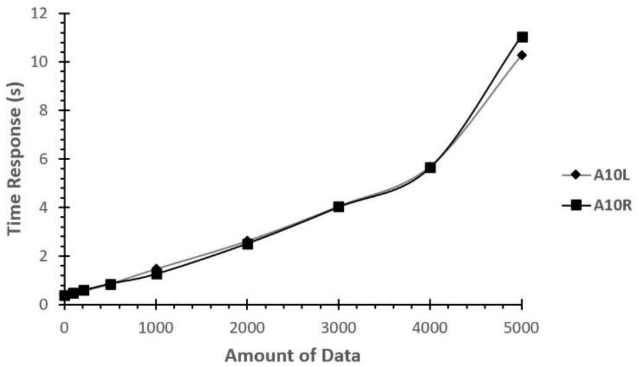

Figure 7. The chart of the testing result of website response speed

Based on the chart shown that the data displaying website response times for the data number of 1, 100, 200, 500, 1,000, 2,000, 3,000, 4,000, 5,000 consecutively were 0.404 ± 0.059 s, 0.505 ± 0.058 s, 0.557 ± 0.072 s, 0.851 ± 0.074 s, 1,463 ± 0.170 s, 2,618 ± 0.190 s, 4,051 ± 0.473 s, 5,697 ± 0.638 s, and 10,283 ± 4,200 s on A10L sensor system device, and 0.415 ± 0.051 s, 0.499 ± 0.057 s, 0.593 ± 0.052 s, 0.871 ± 0.067 s, 1,270 ± 0.090 s, 2,522 ± 0.198 s, 4,022 ± 0.605 s, 5,646 ± 0.362 s, and 11,069 ± 4,399 s on A10R sensor system device. Based on the data, a result was obtained that the difference of data number on the database influenced the website page opening time significantly.

4. CONCLUSION

Based on the research result, it could be concluded as follows: LiDAR lite V.3, IP camera, and Raspberry Pi could be used well for detection systems and FOD monitors that could detect objects in real-time and the result could be accessed directly. The placement of both FOD sensor system devices with a 5 meters distance was proven to be effective to extend the system detection area with a maximum detection distance of 5 meters on a -40 to 40-degree detection angle. A set up of LiDAR lite V.3, Raspberry Pi, and motor servo could provide distance information and position angle of the object to IP camera so that IP camera could move to the position determined. Information of distance and position angle could also be accessed directly once the detection process is done. The testing of website page features with black-box testing showed the result that the features that had been designed could work as planned. The number of data on the expanding database made the process of opening the website page took longer time on the data number of 5,000 to 10,283±4,200 s for A10L sensor system device and 11,069±4,399 s on A10R sensor system device.

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